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# A Data Structure for 3D Synthetic Environment Reconstruction

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## ABSTRACT

The Digital Mapping, Charting and Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has investigated an extension to the National Imagery and Mapping Agency's (NIMA's) current Vector Product Format (VPF) known as VPF+. This paper describes VPF+ and a prototyped 3D synthetic environment using VPF+. The latter was designed as a 3D Geographic Information System (3D-GIS) that would assist the U.S. Marine Corps with mission preparation and also provide onsite awareness in urban areas. The prototype supplements the more traditional 2D digital-mapping output with a 3D interactive synthetic environment

## 1. INTRODUCTION

The Digital Mapping, Charting and Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has investigated an extension to the National Imagery and Mapping Agency's (NIMA's) current Vector Product Format (VPF) known as VPF+ [1, 2]. VPF+ adds a new level of topology called Level 4 Full 3D Topology (Level 4). The topologic information encompasses the adjacencies involved in 3D manifold and non-manifold objects, and is described using an extended Winged-Edge data structure called *3D Non-Manifold Winged-Edge Topology*. This level of topology is intended to facilitate the use of VPF in the Three-Dimensional Synthetic Environment (3D SE) generation process by supporting a wide range of three-dimensional features.

We have prototyped VPF+ in a 3D Geographic Information System (3D-GIS) that would assist the U.S. Marine Corps with mission preparation and also provide onsite awareness in urban areas. These operations require practice in physically entering and searching both entire towns and individual buildings. Our prototype, therefore, supplements the more traditional 2D digital-mapping output with a 3D interactive synthetic environment in which users may walk or fly across terrain, practice entry of buildings through doors and windows, and gain experience navigating the interiors of buildings.

## 2. OUR VPF DATABASE WORK

Since 1994 we have been active in the development of a digital mapping database, the Geospatial Information Database (GIDB). The GIDB is an object-oriented, CORBA compliant spatial database. Although the predominant data type in the GIDB is NIMA produced VPF data, the GIDB stores multiple data types from multiple sources. The data is accessible both locally and remotely over the web through a Java Applet.

The GIDB includes an object-oriented data model, an object-oriented database management system (OODBMS, currently Gemstone<sup>®</sup>) and various spatial analysis tools. The spatial analysis tools include spatial query interaction, multimedia support and map symbology support. Users can query the database by area-of-interest, time-of-interest, distance and attribute. Interfaces are implemented to afford compatibility with Arc/Info and Oracle 8i, among others.

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The National Imagery and Mapping Agency and the U.S. Marine Corps Warfighting Lab sponsored this work.

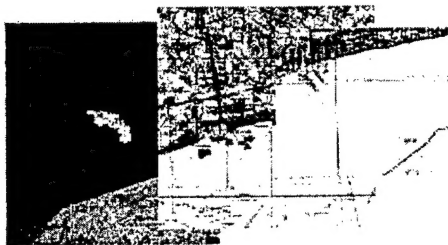


Figure 1: 2D Maps of the Millennium Dragon Exercise Area, Gulf of Mexico Produced by NRL's GIDB.

Figure 1 shows an example of data access over the web through the applet. The area-of-interest shown is for a portion of the U.S. Marine Corps Millennium Dragon Exercise that took place in September 2000 in the Gulf of Mexico. The user was able to access the area of interest via the GIDB applet, bring in CIB imagery and overlay it with various VPF vector data from the Digital Nautical Chart, Mission Specific Data Sets and survey data from the Naval Oceanographic Office. The user was then able to zoom in, replace CIB with CADRG imagery, and then zoom in further to see more of the detail of the Vector data around the harbor in Gulfport, Mississippi.

### 3. THE VPF+ DATA STRUCTURE

VPF has widespread use and there are numerous VPF databases, but VPF is primarily designed for 2D-mapping. In order to facilitate its use in the 3D SE generation process, we designed VPF+ as a superset of VPF. This superset introduces an additional level of topology called Level 4 Full 3D Topology (Level 4) to accomplish 3D modeling. A boundary representation (*B-rep*) method is employed. B-rep models 3D objects by describing them in terms of their bounding entities and by topologically orienting them in a manner that enables the distinction between the object's interior and exterior.

The topologic adjacencies of three-dimensional manifold and non-manifold objects in the SE are described using an extended Winged-Edge data structure, referred to as '*Non-Manifold 3D Winged-Edge Topology*'. Geometric information includes both three-dimensional coordinates and Face and Edge orientation. Although this paper is restricted to planar geometry, curved surfaces can also be modeled through the inclusion of parametric

equations for Faces and Edges as associated attribute information.

*Non-manifold* objects are those in which one of the following conditions exist: (1) exactly two faces are not incident at a single edge, (2) objects or faces are incident only through sharing a single vertex, or (3) a dangling edge exists in [3]. A dangling edge is one in which the edge is not adjacent to any face. Non-manifold objects are commonplace in the real world, and they should be found in a synthetic environment (SE).

Level 4 is a full 3D topology that is capable of representing comprehensive, integrated 3D synthetic environments. Such an environment can include the terrain surface, objects generally associated with the terrain surface such as buildings and roads, and it can include objects that are not attached to the terrain but are rather suspended above the terrain surface or below a water body's surface.

### 4. THE PROTOTYPED SYNTHETIC ENVIRONMENT

The synthetic environment prototype consists of the U.S. Marine Corps' Military Operations in Urban Terrain site at Camp LeJeune, North Carolina. The MOUT site is a small city built by the Marine Corps for urban combat training, and it consists of approximately 30 buildings constructed in a variety of shapes and sizes to resemble what might be expected in an actual urban area. Since the area is supposed to resemble a combat environment, some are constructed to exhibit various degrees of damage. There is also a transportation network and the usual urban features associated with this type of setting such as trees, park benches, planters, flag poles, etc.

Data for the site is readily available, which allowed for construction of a detailed 3D SE that closely matched its real world counterpart. MOUT buildings that exhibit damage, for example, are reproduced in the prototyped SE to show the same elements of damage. The VPF+ data structure and digitization of the buildings' construction drawings allowed us to re-create the MOUT site with great geometric accuracy, including the buildings' interiors.

#### 4.1 Source Data

The flow chart shown in Figure 2 diagrams the source data and how it data was used in the import process. Data used to construct the prototype consisted of traditional VPF data, imagery, building plans, area surveys, and high-resolution DTED. The building plans allowed

generation of accurate synthetic models of the buildings, while the imagery data provided answers to questions that remained open after working with the plans. Data obtained from a standard VPF database was imported into the prototype database from four coverages: population, transportation, industry and hydrology. This data was useful for positioning 3D objects and was also used to generate 2D map views.

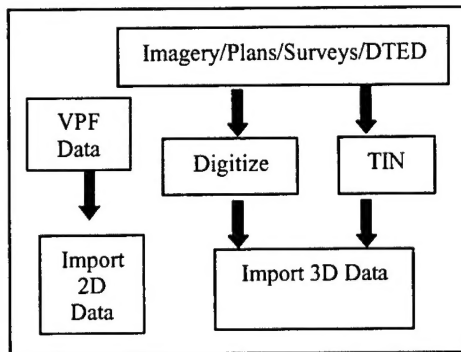


Figure 2: Data Import Flow Chart

ArcInfo® was used to create an interim elevation model of the elevation data in the form of a Triangulated Irregular Network (TIN). This allowed reduction of terrain elevation data from over 90,000 elevation points for an area of only approximately 600 meters square, to approximately 1000, greatly improving performance. Since this geographic area is known to be relatively flat, the remaining elevation points were considered adequate to approximate the terrain. Lines forming the buildings' footprints were used as constraints to guarantee a uniformly flat terrain under each of the buildings.

#### 4.2 Obtaining Detailed 3D Features

A digitizer was used in order to raise flat floor plans into 3D. The digitizer allows a user to employ a mouse with digital images of the floor plans to define the 3D building on screen, to properly place doors and windows, and to define the VPF+ topology for the faces and building. Individual faces, for example, can be defined as either part of the boundary of the building or as being inside a building, and the out direction for boundary faces can be specified. The digitizer screen coordinates are georeferenced to their correct real-world locations at import and the non-manifold topology is maintained. Detailed attribution for the appearance of buildings and point features as well as road width was lacking from the source data.

#### 4.2.1 Handling Generic Point Feature Data

The VPF+ prototype database contains point feature data and the identity of the generic library models used to represent each point feature. Library models were created for each of the types of point features involved - street lights, fire hydrants, flag poles, park benches and planters, for example. The 3D run-time engine renders the correct model representing each point feature.

#### 4.4 The Prototype Interface

The prototype provides a 3D synthetic environment alongside a more traditional 2D digital map. The map view offers general orientation and feature identification, while the 3D SE complements this with an immersive experience of the three-dimensional environment [4]. The combination should prove beneficial to a variety of uses. A commercial-off-the-shelf OODBMS was used for the prototype database. Java2 and the Java3D API were used for interface into the database for rendering by area-of-interest. The Java3D API provided reasonable performance for 3D interaction and easy implementation.

The interface into the prototyped database allows the user to query a world map for an area-of-interest by dragging the mouse. Figure 3 shows a 2D-map view of the prototyped area that resulted from such a query. The user can then elect to have a 3D SE of the area shown on the map generated by pressing the appropriate button.

Figures 4 - 6 show 3D views of the SE for the area shown on the map in Figure 3. Buildings take on their real-world appearance. Full building interiors are also included.



Figure 3: 2D Map of the MOUT Facility

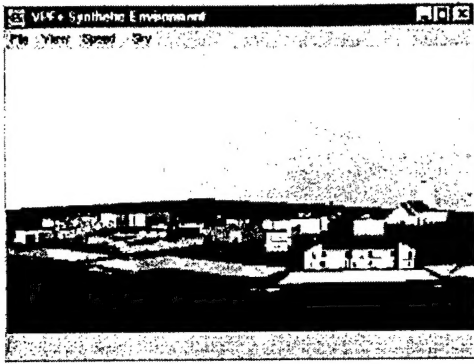


Figure 4: 3D View of the MOUT Facility from the Southeast

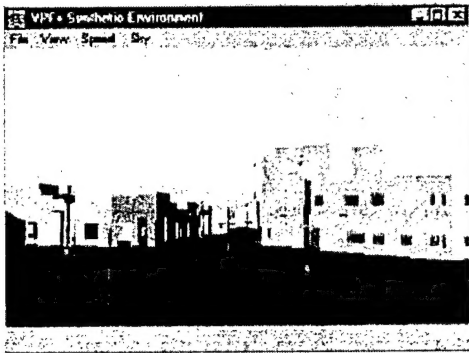


Figure 5: Inside the MOUT Facility

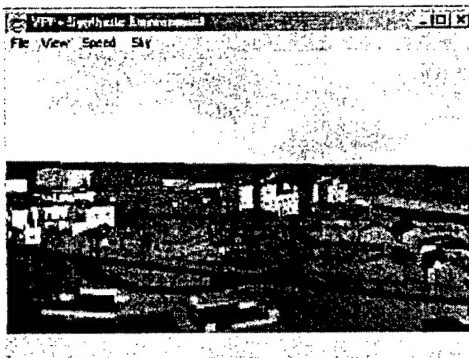


Figure 6: View of the MOUT Facility from the West

The interface allows the user to move through the SE and into and out of buildings by use of the arrow keys. Movement can be by walking on or flying above the terrain. Drop-down menus allow the user to change speed, background texture and lighting conditions. Altering lighting conditions allows the viewer, for example, to obtain both day and night views of the 3D SE.

A feature is also provided that allows the user to track his position in the 3D SE. When

activated, this feature places an icon on the map corresponding to the user's position in the 3D SE. As the user moves through the SE, the position of the icon is updated. The icon is oriented to correspond to the user's orientation in the SE.

## 5. OBSERVATIONS

This paper has described VPF+, an extension of NIMA's VPF product that provides an extended winged-edge data structure called 3D Non-Manifold Winged-Edge Topology. VPF+ supports many topological adjacency relationships for a wide range of objects likely to be modeled in a 3D SE. VPF+ should be useful for commercial as well as the more traditional modeling and simulation applications, especially for developers who want to extend their geographic information system capability to add 3D topology.

The prototype showed VPF+ in action for U.S. Marine Corps MOUT Facility at Camp LeJeune, North Carolina. The prototype database used an off-the-shelf OODBMS to store 2D and 3D data. Data was extracted on demand by the user's area-of-interest.

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